Final Degree project

Bachelor’s degree in

Industrial Technology Engineering

Analysis of the Impact of Photovoltaic Generation in a nearly Zero-Energy Building

REPORT

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Abstract

This report contains the analysis of different measures applied to a single-family house, in the region of Asturias, in order to be considered a nearly Zero-Energy Building.

The situation and the climatic conditions are studied to see its impact on the architectural design of the house, the selection of specific isolation materials and the use of appropriate renewable energy systems.

The renewable energy systems selected are a biomass heating system and a water/air heat pump.

A photovoltaic system is designed, according to the energetic conditions of the house, to cover the electrical demand. The aim is to reduce the environmental impact and also the electrical bill.

The installation designed consists in a solar field made of 14 photovoltaic panels to generate the 100% of the electric demand of the house. It is a grid-connected and built-integrated system. No batteries will be used, and the energy not consumed is sent to the grid.

The fact that no batteries are used and that the exceeding energy is sent to the electric company, contribute to economic viability of the system.

Contents

1. Preface

Global warming is a reality that nobody can ignore. Over the years, a lot of scientists have collected data to prove that climate change is a fact. Most scientists believe that human activity, such as burning of fossil fuels and the resulting build-up of greenhouse gases in the atmosphere, have influenced this warming trend.

As evidence, according to data from NASA, global temperature in 2013 averaged 14.6 degrees Celsius, roughly a degree warmer than the twentieth-century average.

Another important change is the fast melting of the glaciers. These have been studied for many years by scientist because it gives a lot of information related to the climate change.

For example, when an ice core or an ice sheet is taken from the glacier it is possible to study the changes in the composition of the atmosphere, the variations of the temperature and the different types of vegetation throughout the years. Each one shows that the world is changing fast.

In the picture below you can see the transformation of the Rhône glacier.

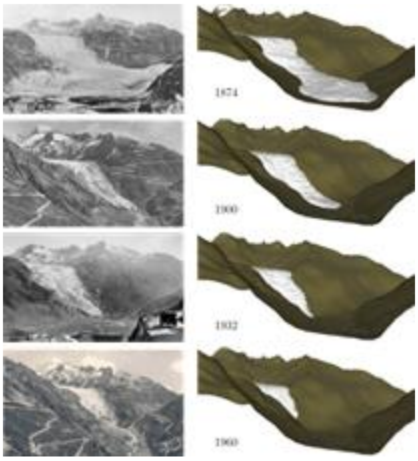

Figure 1.1*:* Photographs of the Rhône glacier (left) and simulation (right) **¡Error! No se encuentra el origen de la referencia.**

The facts exposed are only some proofs that climate change started many years ago. Moreover, the situation is getting worse as time goes by. For these reasons, some countries have been trying to establish different global measures to confront the problem.

One of the agreements is the **Kyoto Protocol to the United Nations Framework Convention on Climate Change** which almost everyone knows.

On 11 December 1997, the parties signed a Protocol in Kyoto, Japan, in which they agree to reduce the emission of greenhouse gases. Nevertheless, the emission targets are not the same for all the countries because not every country has the same capacity to apply the reductions. Furthermore, there are some countries that have produced more emissions than the rest, such as Great Britain, which started the Industrial Revolution on the second half of the 18th century.

Since the moment that European Union started to improve its politics towards the climate change a lot of directives have been approved. One of them was The Energy Performance of Buildings Directive (EPBD 2010/31/EU), this one established that all new constructions, from 31st December 2020, will have to reach the standard nearly Zero Energy Building (nZEB) and the same for all new public buildings during the 2018. This implies a large-scale deployment of this kind of buildings.

This directive about the buildings is so important because the energy that these consume represent the 40% of the total energy produced in Europe. Even in a few years it could be a 60%, due to an increase of electric cars. However, a reduction of energy demand on buildings can imply a 20% reduction of the impact on the environment.

2. Introduction

This report contains the study of architectural and technical solutions applied to the building of an nZEB house. The main objectives of the study are the following:

- Verify that all the regulations that define an nZEB building are met.
- Evaluate the energetic demands of the house
- Design a photovoltaic installation to cover the electrical demands of the house
- Evaluate the environmental impact and the economic viability of the photovoltaic system

In order to achieve these objectives, this work is divided into several parts.

First, a review of the general theory of nZEB buildings and photovoltaic systems.

Then, the case study is analysed. The location and characteristics of this single-family house are described. In this part the climate and solar conditions of the site and also the size, shape and orientation of the house are described because these are relevant to the present study.

An energetic study of the house is performed in order to check whether the nZEB standards are met. From this the energetic demands of the house are stablished.

Once the energetic demands of the house are determined we can proceed to size the photovoltaic system. We do this using the solar irradiation levels on the site, orientation and inclination of the panels, number of panels, power of the inverter, etc.

When the PV system is defined the complementary electrical installation is explained. This consists on the measuring equipment, security protections, cables and earth connections.

The last part consists on sections explaining the regulations used in the project, the environmental impact and the economic viability.

3. nZEB (*nearly Zero Energy Building*)

Buildings are a strategic focus of European Union to reduce the energy consumption and to achieve a sustainable economy. Therefore, The European Commission have approved several policies related to the buildings. Some of them represented by the recast of the Energy Performance of Building Directive (EPBD), which introduces *nearly Zero Energy Building.*

3.1. Definition of nZEB

First, it's important to analyse the term "ZEB" because it has two different definitions that could lead to confusion.

On one hand, it can be used as a Zero Energy Building, which refers to the energy consumed by a structure in its day-to-day operation. On the other hand, it can mean a Zero Emission Building that refers to the carbon emissions that are released to the environment as a result of its operation.

In general terms, a ZEB can be described as a residential or commercial building with greatly reduced energy needs and/or carbon emissions, achieved through efficiency gains, such as the balance of energy needs supplied by renewable energy. [2]

Also, we have to be careful with the term NZEB that means 'Net Zero Energy Building', which refers to the energy use of 0 kWh/ (m^2 a) primary energy.

Moreover, on the last years several concepts and categories have been introduced referred to the term 'ZEB'. This new concepts and categories depended on different aspects. As an example, Torricellini defined four different concepts around Zero Energy Buildings that depended on boundaries and metrics. [3]

However, this project is going to focus on the term nearly Zero Energy Buildings and not into the other ones.

The Energy Performance of Buildings Directive (EPBD 2010/31/EU) presented for the first time the definition of nearly Zero Energy Building (nZEB).

As defined in the art.2, a 'nearly Zero-Energy Building' is a building with very high-energy performance that should cover the nearly zero energy (or at least a very low amount of it) required by on site or nearby energy production from Renewable Energy Source (RES).

As it can be seen, it gives a lot of space for national interpretation and doesn't give minimum or maximum harmonized requirements, nor details of the quantitative indices to be considered (i.e., CO2 emissions, amount of renewable energies to be integrated, performance targets, etc.). Consequently, European countries have adopted their own definition, so that there are many differences between them, and the conditions aren't the same. Therefore, there are countries that have made a bigger effort than others.

For example, in France, new residential buildings must accomplish a primary energy consumption lower than 60KWh/(m2·year). Whereas in Austria, the primary energy required in new residential buildings is less than 160KWh/(m2·year).

In the recent years, an important goal that scientists are trying to achieve is a professional framework that contains all the relevant aspects characterizing nZEB and to help each country define a reliable definition in compliance with the national law, the country's policy targets and specific local conditions.

In this regard, the REHVA Task Force proposes a technical definition for nearly zero energy buildings required in the implementation of the Energy performance of buildings directive recast. Energy calculation framework and system boundaries associated with the definition are provided to specify which energy flows in which way are considered in the energy performance assessment. The intention of the Task Force is to help the experts in the Member States in defining the nearly zero energy buildings in a uniform way. [4]

REHVA launched another version in cooperation with European standardization organization CEN to afford an available methodology suitable for the implementation in national building codes for the primary energy indicator calculation. The last version was prepared to complement with specifications for nearby renewable energy and for the contribution of renewable energy use. A set of the system boundaries and equations are given for energy need, energy use, delivered and exported energy, primary energy and for renewable energy ratio calculation. With these definitions and energy calculation framework, primary energy indicator and renewable energy ratio can be calculated as required by the directive.[5] Moreover, it is important the methodology to calculate the primary energy indicator because many countries use it to know if a building is considered nZEB.

Consequently, the text below presents the calculation methodologies and its related definitions.

The basic energy balance of the delivered and exported energy and system boundaries for the primary and renewable energy calculations for on site assessment, are shown in *Figure 3.1*.

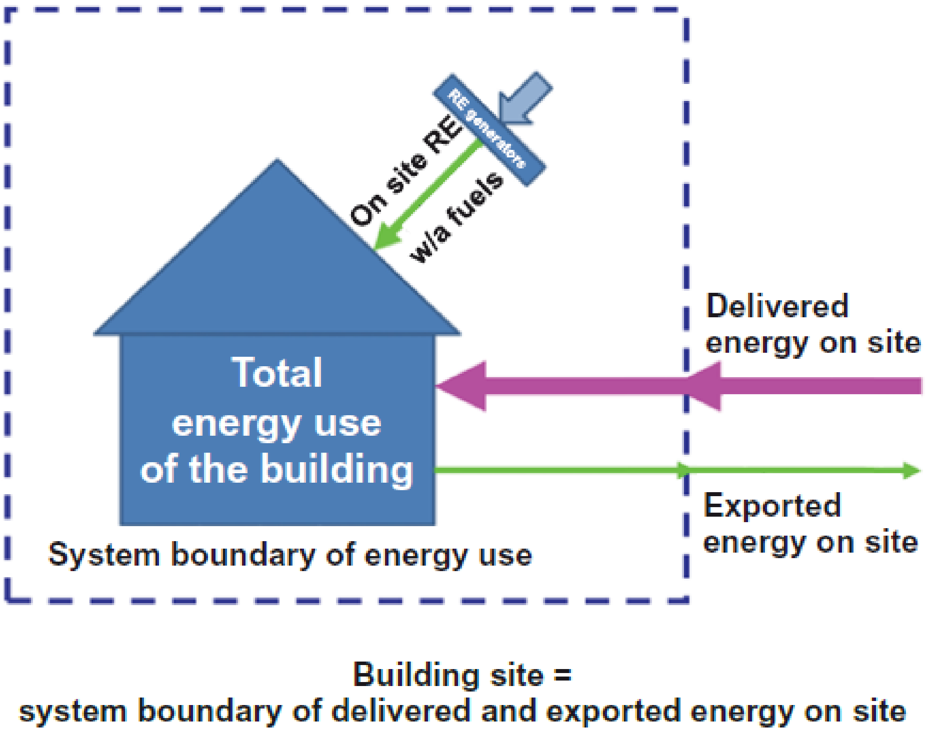

Figure 3.1: System boundaries for on site assessment connecting a building with on site renewable energy sources to energy networks.[5]

According to *Figure 3.1*, for delivered electricity and thermal energy we have:

$$E_{us,el} = \left(E_{del,el} - E_{exp,el}\right) + E_{ren,el} \tag{3.1}$$

$$E_{us,T} = \left(E_{del,T} - E_{exp,T}\right) + E_{ren,T} \tag{3.2}$$

E_{us} total energy used KWh/ a;

E_{del} delivered energy on site (kWh/a);

E_{exp} exported energy on site (kWh/a);

E_{ren} on site renewable energy without fuels (kWh/a);

T thermal energy;

el electricity; [5]

Despite what is exposed in *Figure 3.1*, some buildings expand their production capacity with a new nearby renewable energy plant. Therefore, the system boundary showed must be extended. Consequently, to calculate nearby delivered and exported energy, this extra amount of energy produced by the nearby plant must be added/subtracted to the delivered/exported energy flows on site. This change is shown below in *Figure 3.2*.

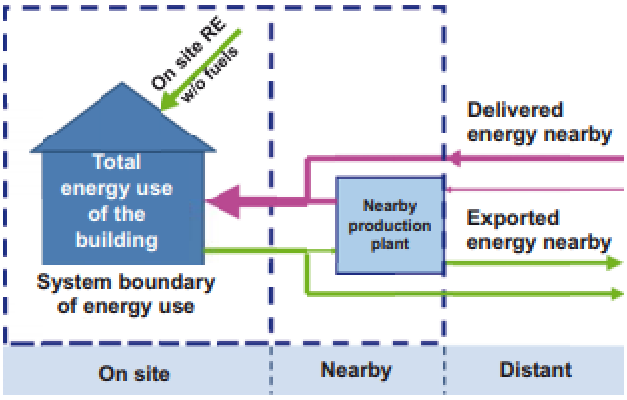

Figure 3.2 : Nearby assessment boundary to be used when a new renewable energy plant is added.[5]

So, it's time to present the primary energy indicator, which sums up all delivered and exported energy into a single indicator. Primary energy and primary energy indicator are calculated from delivered and exported energy with national primary energy factors as:

$$E_{P,nren} = \sum_i (E_{del,i} \cdot f_{del,nren,i}) - \sum_i (E_{exp,i} \cdot f_{exp,nren,i}) \tag{3.3}$$

$$EP_P = \frac{E_{P,nren}}{A_{net}} \tag{3.4}$$

EP_P	primary energy indicator (kWh/(m² a));
$E_{P,nren}$	non-renewable primary energy (kWh/a);
$E_{del,i}$	delivered energy on site or nearby (kWh/a) for energy carrier i;
$E_{exp,i}$	exported energy on site or nearby (kWh/a) for energy carrier i;
$f_{del,nren,i}$	non-renewable primary energy factor (-) for the delivered energy carrier i;
$f_{exp,nren,i}$	non-renewable primary energy factor (-) of the delivered energy compensated by the exported energy for energy carrier *i*, which is by default equal to the factor of the delivered energy, if not nationally defined in other way;
A_{net}	useful floor area (m²) calculated according to national definition.

The following example is intended to clarify all concepts and formulas that have been exposed until this point. *Figure 3.3* shows the exchange of energy between different system boundaries for on site assessment. With this example it's easier to understand that there are small system boundaries within the building site boundary.

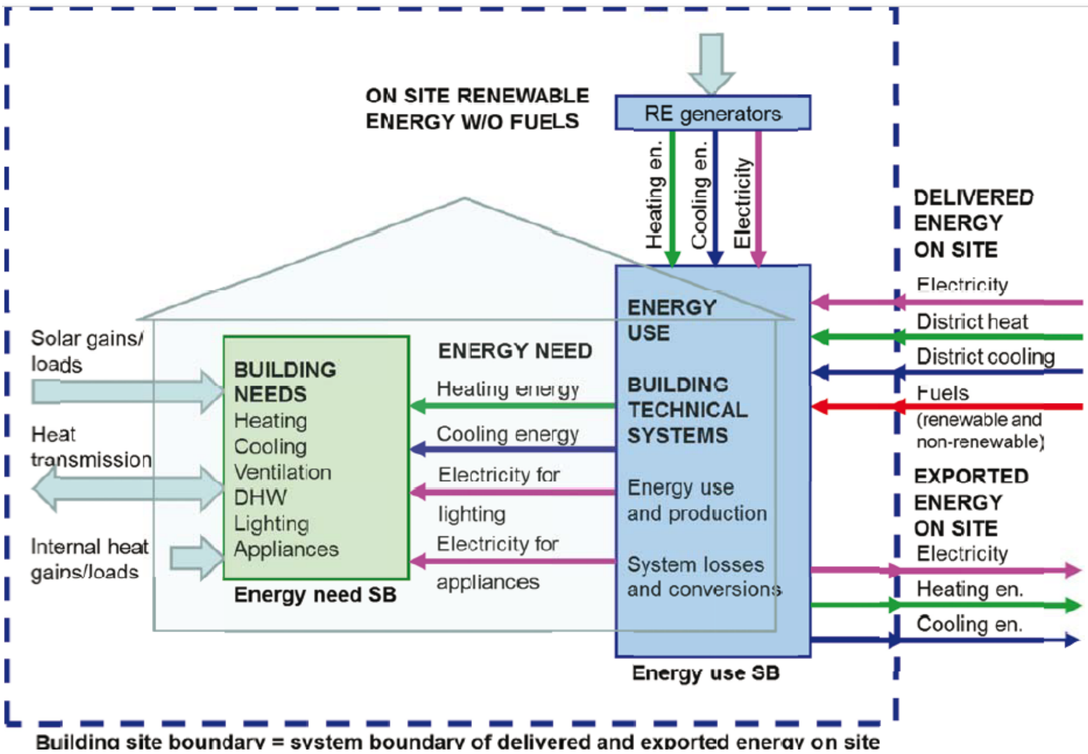

Figure 3.3 : Three system boundaries (SB) for on site assessment (nearby production not linked to the building), for energy need, energy use and delivered and exported energy calculation.[5]

The Renewable energy ratio (RER) calculation is useful to obtain the percentage of renewable energy use. Therefore, all renewable energy sources must be taken into account. These include solar thermal, solar electricity, wind, hydroelectricity, etc. and the energy captured from ambient heat sources by heat pumps and free cooling, off site renewable energy and renewable fuel. However, each building uses different ways to obtain energy and it's important to find the best way to reach the desired amount of energy.

The renewable energy ratio is calculated relative to all energy used in the building, in terms of total primary energy. For on-site and nearby renewable energy, the total primary energy factor is 1.0 and the non-renewable primary energy factor is 0.

Total primary energy-based RER equation is the following

$$RER_P = \frac{\sum_i E_{ren,i} + \sum_i \left(\left(f_{del,tot,i} - f_{del,nren,i} \right) E_{del,i} \right)}{\sum_i E_{ren,i} + \sum_i \left(E_{del,i} \cdot f_{del,tot,i} \right) - \sum_i \left(E_{exp,i} \cdot f_{exp,tot,i} \right)} \qquad (3.5)$$

RER_P	renewable energy ratio based on the total primary energy
$E_{ren,i}$	renewable energy produced on site or nearby for energy carrier *i*, kWh/a
$f_{del,tot,I}$	total primary energy factor (-) for the delivered energy carrier *i*
$f_{del,nren,I}$	non-renewable primary energy factor (-) for the delivered energy carrier *i*
$f_{exp,tot,I}$	total primary energy factor (-) of the delivered energy compensated by the exported energy for energy carrier *i*
$E_{del,I}$	delivered energy on site or nearby for energy carrier *i*, kWh/a
$E_{exp,I}$	exported energy on site or nearby for energy carrier *i*, kWh/a.[5]

Nevertheless, these two indicators are not the only ones used by the member states of the European Union. For example, to classify buildings on Germany or Switzerland, they use the heat demand <15 kWh/m2a, the cooling demand <15 kWh/m2a, and the primary energy indicator <120 kWh/m2

3.2. nZEB in Spain

In recent years, Spain has improved the energy efficiency of buildings in order to respect the environment and to comply with the directives approved by the European Union. Therefore, some essential changes have been approved to try to be a green country.

Figure 3.4:Classification according to the energy efficiency of the building

In 2007, for the first time in Spain, the government ruled that all new buildings must be classified according to the energy consumed. Later, the Royal Decree 235/2013 was approved to regulate the procedures about efficiency energy for buildings. Consequently, all buildings that are rented or transmitted must be classified with a certificate. On this certificate an Energy Efficiency Class is assigned to the building. This classification starts with Class A for the most energy efficient and goes through Class G for the worst, as we can see on the left picture. Each building will be classified according to the emissions of carbon dioxide.

Therefore, some documents and computer programmes have been developed to implement this classification. One of them is CE3X, it is a "Recognized Document of Energy Certification for Existing Buildings". It has been developed by Efinovatic and the National Centre for Renewable Energies (CENER). This team is responsible for the maintenance of CE3X and the development of the new versions. Using this software, you can certify in a simplified way any type of building: residential, small tertiary or large tertiary. CE3X adapts to the great variety of situations that a certifying technician must face, allowing different possibilities for entering the building's data.

In Spain, the requirements that a building must comply are explained in the Edification’s Technical Code ('Código Técnico de la Edificación, CTE'). The definition and parameters for a nearly Zero Energy Building are contained in this document. Specifically, it is in the DB-HE document where we find the nZEB definition:

> ***nearly* Zero Energy Building***:* A building that complies with the regulatory requirements established for newly constructed buildings in the different sections of this basic document (DB-HE).[6]

The document is divided into the following six parts:

- Limitation of energy consumption
- Limitation of energy demand
- Efficiency of thermal facilities
- Energy efficiency of lighting facilities
- Minimum solar contribution of sanitary hot water
- Minimum photovoltaic contribution of electrical energy

3.3. Passive measures to reach the nZEB standards

One of the main functions of buildings is to control thermally an environment, modifying external conditions (determined by climate) to guarantee the welfare of the occupants.

The concept design of buildings and their architectural characteristics are the most profitable aspects when it comes to the project an nZEB. These first steps that don't necessarily imply specific machinery or appliances, are referred as *passive strategies*. In order to reach an nZEB, a correct and optimized bioclimatic design will be required to minimize the energy demand for heating, cooling, hot water and lighting.

Some of the main factors that determine the energy of a building are:

- Orientation
- Solar radiation
- Exterior temperature
- Infiltrations

- Ventilation
- Internal thermal loads
- Compactness
- Window wall ratio
- Shadow elements and thermal bridges

Therefore, the energy demand necessary to obtain the desired comfort conditions of a building will depend on the geometrical and thermal characteristics of the building, as well as its use and internal thermal loads.

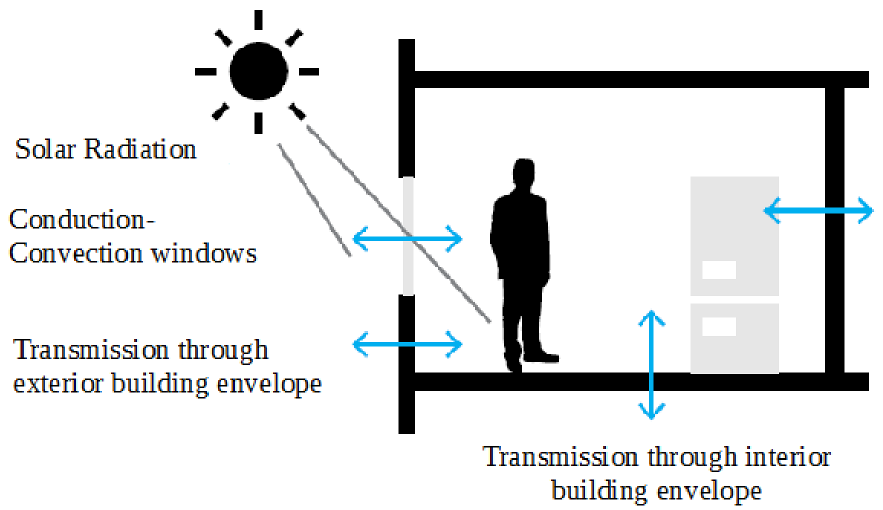

Figure 3.5: Energy exchange between interior and exterior through the envelopment of the building. [7]

3.3.1. Geometry and Shape Factor (Compactness)

The geometry and the shape factor of a building can have a significant impact on the energy consumption because the energy exchange between its interior and exterior is realized through the surface of the building envelope. Therefore, if the surface increases the energy exchange will do the same.

For example, on extreme climates, this exchange of energy is bad because some of the energy produced inside the building will be lost. Hence, a higher amount of energy will be needed to comfort the place. However, in soft climates this exchange is good because comfortable outside conditions will benefit the interior of the building.

Nevertheless, shape factor and window wall ratio changes can modify the amount of natural lighting and produce an increase on the consume of artificial lighting.

3.3.2. Orientation

The orientation of a building is another key factor to be considered when trying to reduce the energy consumption. It has impact in:

- **Capture of solar radiation of the building**: This will depend on the orientation of the holes and facades.
- **Natural ventilation capacity:** Orientation of the building in relation to the direction of the predominant winds.

3.3.3. Envelopment

The success in the choice and execution of the thermal envelopment is a really important factor for the design and construction of an nZEB. The thermal envelope of a building is formed by its enclosures, which separate living spaces from the outside environment (air, terrain or another building) and the interior partitions that separate living spaces from non-habitable areas.

Through the building envelopment, the following energy gains and losses occur:

- Transmission throughout the opaque elements (habitable zone – exterior zone)
- Transmission throughout the interior opaque elements (habitable zone – non-habitable zone)
- Conduction-convection throughout the windows (habitable zone – exterior zone)
- Solar radiation throughout the openings (habitable zone - exterior zone)
- Uncontrolled infiltration of air (habitable zone – outer zone) due to the permeability of the envelope in the air or the non-hermeticity of the enclosures.

3.4. Active measures to reach the nZEB standards

First, the geometry and the thermal envelope have been chosen with the purpose to reduce the energy consumption of the house. After, the optimum systems must be defined in order to supply the energy demand with the minimum consumption of primary energy and thus cut carbon dioxide emissions. Therefore, the best way to achieve these requirements is using renewable energies.

Energy consumption in buildings can be defined as:

$$Energy\ Consumption = \frac{Energy\ Demand}{System\ Performance} \tag{3.6}$$

From this formula we can extract several ideas to reduce energy consumption. For example, some strategies to carry out are the following:

- Decrease energy demand with passive measures
- Use high-efficiency systems
- Decrease energy consumption using non-renewable energies in order to reduce CO_2 emissions.

Consequently, we can reach to the conclusion that we have to focus on the renewable systems to achieve the nZEB standards. Fortunately, many systems use renewable sources, such as:

- Photovoltaic systems
- Solar water heating
- Wind turbines
- Solar air conditioning
- Water turbines
- Biomass plants

These are some of the possibilities that you can find. However, each one has a wide range of variants and possibilities. In this project, the photovoltaic system has been chosen.

4. Photovoltaic (PV) Systems

4.1. Introduction

Nowadays, we are facing a renewable energy transition. There are many arguments in favour of it, but the two main reasons are the climate change and that renewables, such as solar and wind energy, are becoming cost-effective due to research investments and large-scale implementation of these technologies.

Photovoltaic systems have big advantages. They are silent compared with other power plants that have moving parts. Solar energy is emission-free and requires low maintenance. More importantly, solar energy is generated decentralized so that it is possible to supply electricity where there is no grid. However, it has its disadvantages, such as unpredictable generation because it depends on the weather.

Due to its decentralized generation, the design and operation of the electricity network changes as we add new on-site power plants.

4.1.1. Photovoltaics in the electricity network

Until now, the electricity network used can be defined as a centralized and monodirectional distribution system. At one end of the electricity grid, we have power plants (thermal plants, nuclear plants, hydro-electric plants, etc). These are the only structures generating energy. Electricity flows only in one direction through the transmission lines with an appropriate voltage and intensity to reduce power losses.
At the other end of the electricity grid, we have the loads: factories, houses, offices, etc.

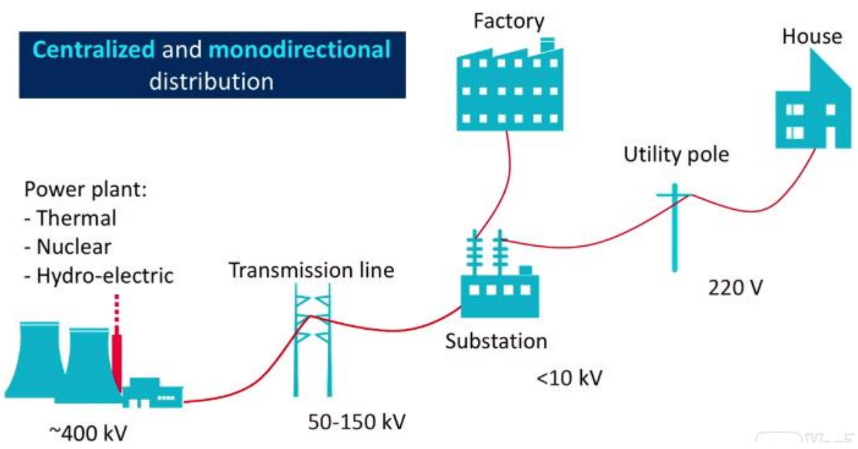

Figure 4.1: Centralized and monodirectional electricity network [8]

When we introduce renewable energy sources, we have an electricity network with decentralized and bidirectional distribution. Therefore, we need a more advanced grid to face these new requirements.

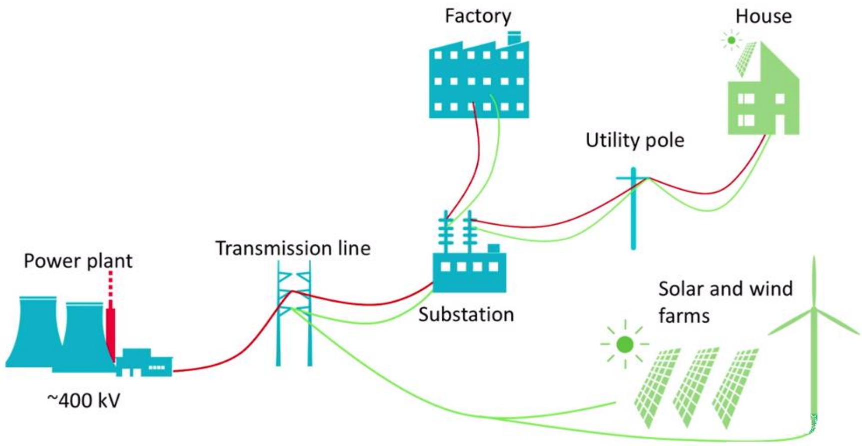

Figure 4.2 : Decentralized and bidirectional electricity network [8]

Hence, future grids must be smart in order to efficiently combine different and unpredictable power sources, it is a topic where much remains to be discovered. Scientists call this type of network *smart-grid*.

4.1.2. Types of photovoltaic systems

PV systems can be divided into two main groups:

- **Stand-Alone:** This installation is used when the cost of maintenance and installation of power lines is not profitable, so that it is for isolated autonomous systems.
- **Grid-Connected*:*** This installation refers to small low voltage generators connected to the electricity distribution network.

Each system can work with or without storage. If PV modules are combined with a complementary method of electricity generation, such as diesel or wind generator they are called *hybrid systems.*

This project deals with a grid-connected system. These systems can be classified into three groups:

- **Directly**: It is the simplest version, PV modules are directly connected to the grid via an inverter, which converts the DC power coming from the modules into AC power for the grid. In Europe, at 230V and 50Hz.

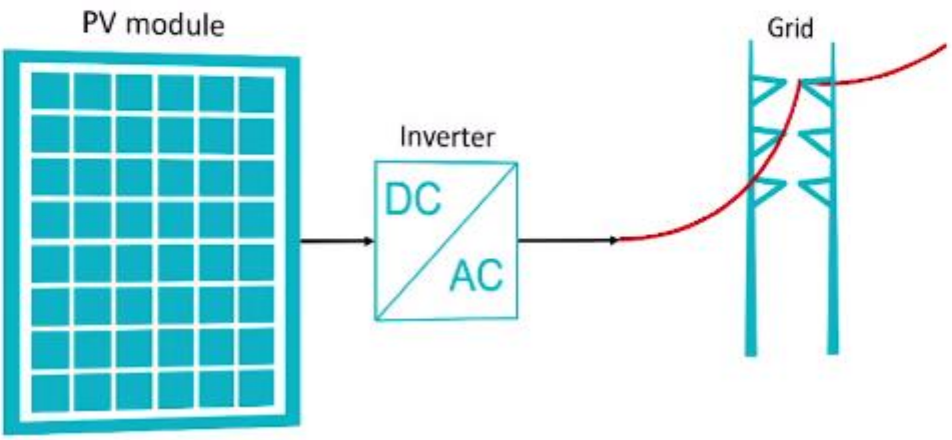

Figure 4.3 : Directly grid-connected system [8]

- **Via household**: The inverter and the AC loads are connected to the distribution board. This device has the role to transfer the generated power into the electricity grid or to AC appliances in the house. These systems do not require batteries and the grid supplies the house with electricity in times of insufficient PV power generation.

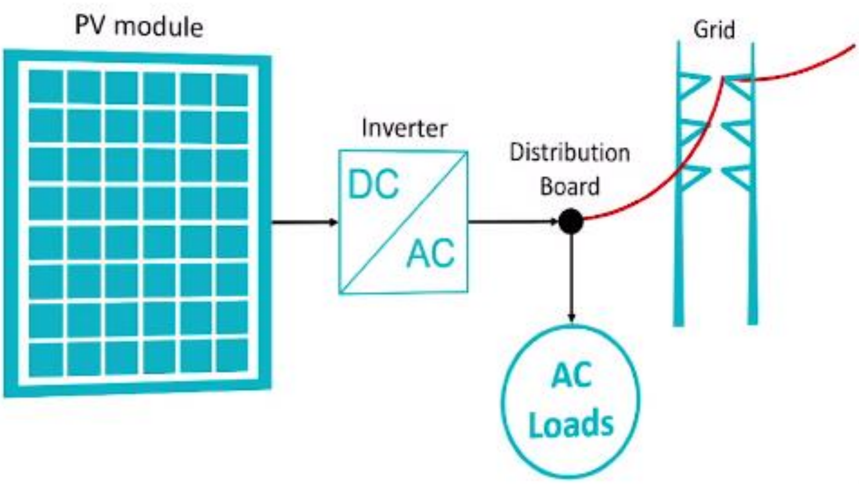

Figure 4.4 : Grid-connected system via household [8]

- **With storage:** Systems with the possibility to store energy. As consequence, a charge controller and batteries are required.

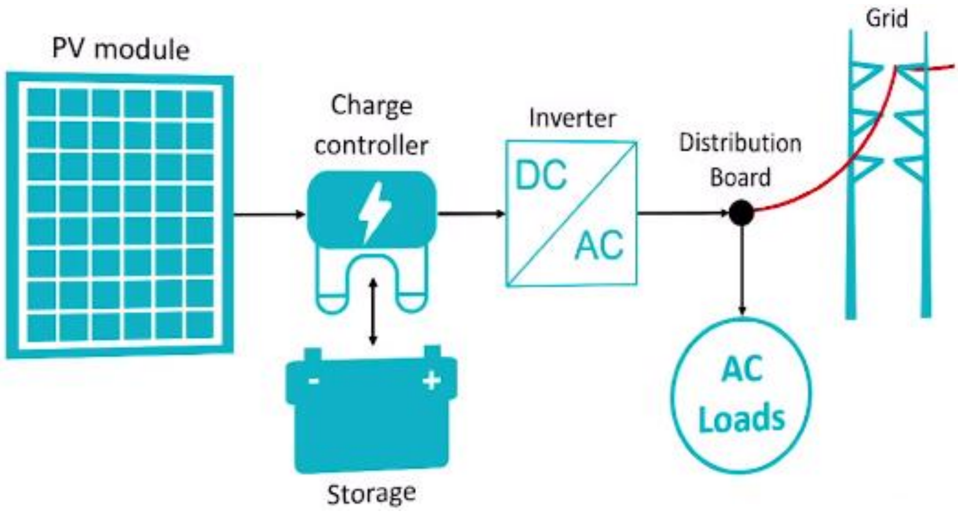

Figure 4.5 : Grid-connected system with storage [8]

4.1.3. Overview of components

Although the most important part in a PV system are the solar panels, many other components are required for a working system. We can divide these into three groups:

- Power generation
- Balance of system
- Outputs

Each group contains different components, which are summarized in the following diagram.

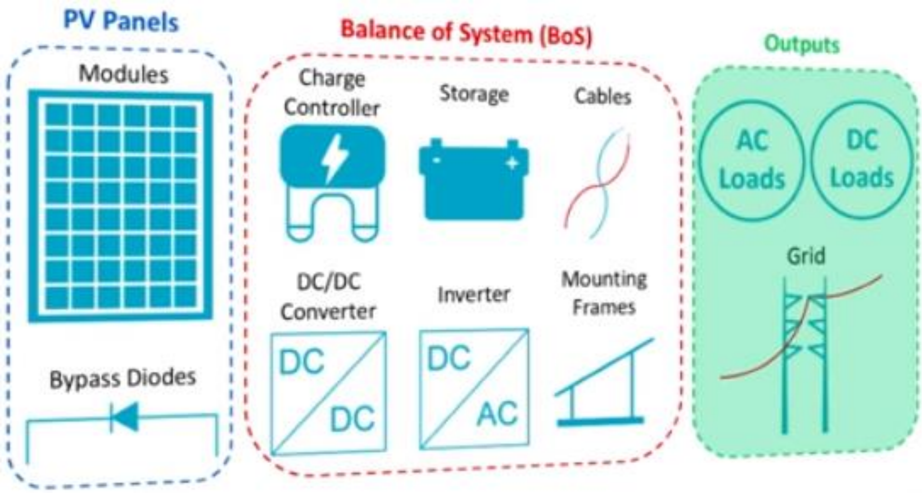

Figure 4.6 : Different groups of components in a PV System [8]

- **Power generation components**

The generation part of a PV system, which are the solar cells. The task of a solar cell is to generate electricity. Using a single solar cell, of course, is not practical for most applications because it delivers a limited amount of power under fixed current and voltage conditions. In order to use the electricity generated by this one, we must connect a number of solar cells, so we form a solar module or PV module.

Once solar cells have been connected, modules are formed by encapsulating the groups of cells with different materials. The encapsulant is added to protect the cells from breakage and environmental influences.

Finally, PV modules can be interconnected in series and/or parallel to achieve the desired power for the system. The resulting combination is called array.

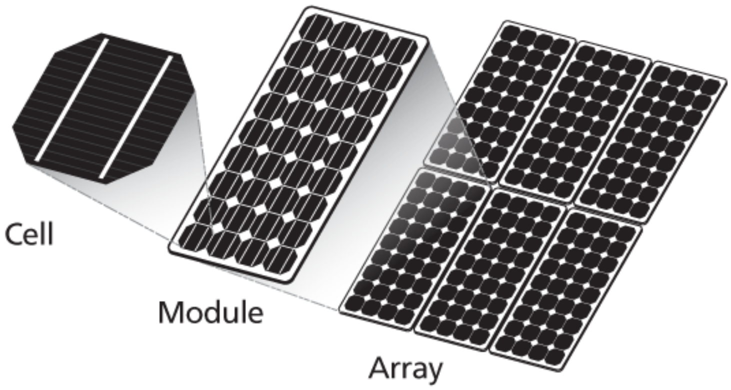

Figure 4.7 : PV Cell, Module and Array [9]

There are different technologies about PV modules on the market, they can be divided into two main groups, wafer based crystalline silicon modules and thin film technologies. They have different purposes. For example, film modules can be made flexible and be used in integrated photovoltaic installations.

In many modules, there are two other relevant components. The first one is the bypass diode that protects the solar cells to avoid a hot-spot. Hot-spots occur when there is a current mismatch in series interconnection. The second one is the blocking diode, which prevents current from flowing from the external circuit into the PV module. This is a consequence of a current mismatch in parallel interconnections.

- **Balance of System components**

The mounting structure fixes the modules and arranges them towards the sun at optimal tilt angle. Cables are used to connect the different components of the PV system to each other, and to the electrical load. It is important to choose cables with enough thickness in order to minimize energy and economic losses. Batteries store energy to be used during the night and in periods of bad weather. We also have power electronics, such as DC-DC converters, DC-AC converters, inverters, charge controllers, etc. they adapt the power flow from the PV array to the rest of the system.

The use of Balance of system components has some drawbacks. When adding a component, the efficiency of the PV system decreases. In addition, they must be replaced more often than other electrical components in the system. For example, batteries have a lifetime of 5 to 10 years compared to the PV modules that usually have a lifetime of 25 years.

- **Outputs of the system**

The outputs of the system include all the connected electric devices and the grid. They are classified depending on their required voltage levels and power consumption.

5. Case Study

The house studied in this project is in Spain, in the autonomous region of Asturias. In the city of Villa that is in the municipality of Corvera de Asturias.

Figure 5.1 : Localization on Google maps

Some of the main characteristics of the place and the house are the following:

- Surface of the house: 147,9 m^2
- Volume of the house: 450,42 m^3
- Single-family house for 4 people
- Height above sea level: 109 metres
- Plot of land: 1830 m^2
- Latitude: 43.52º Longitude: - 5.94º
- Climatic Zone for HE1: C1
- Climatic Zone for HE4: **I**

The house is considered nZEB and its construction has just begun this year (2019). Therefore, we worked with the plans and the data of the house and their virtually simulation.

The following figure is a general plan of the house and the ground, with a simple sketch of the rooms and the outside of the house.

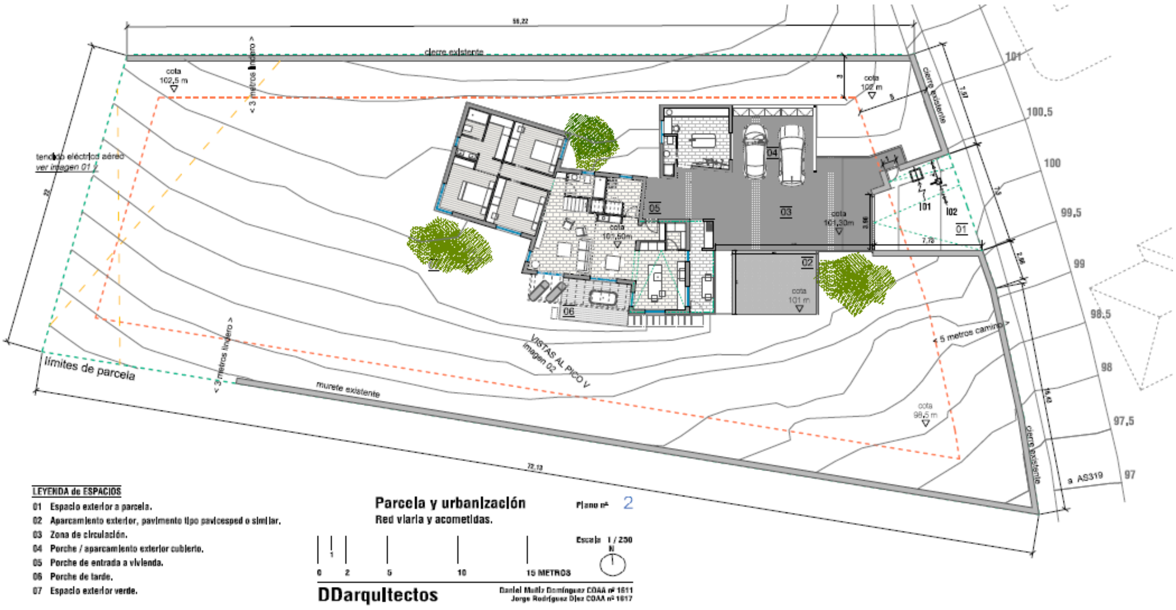

Figure 5.2: General plan designed by DDarquitectos

Figure 5.3: Virtual design of the house made by DDarquitectos

It is a house with two floors, it has the usual main rooms, such as kitchen, living room, bedrooms, corridor, garage, etcetera.

It is important to determine where the solar panels will be located. They can be either free-standing or building integrated.

If the photovoltaic panels are mounted as free standing, they should be on the ground, as far as possible from the house, in order to preserve the big green space surrounding the house, and to minimize the visual impact.

If the photovoltaic panels are fixed as built integrated, it should be on the roofs facing to the south.

The final decision has been to fix photovoltaic panels on the roof because to obtain more space outside, less visual impact and more safety. Built-integrated PV system will be fixed in the highest roof that is facing to the south. Being the highest roof, no part house will overshadow the panels. It is also the biggest one so it can contain all the panels.

Figure 5.4 : Virtual view of the east facade showing the selected roof.

6. Energy Analysis

This part of the project analyses the different passive and active measures applied to the studied building to achieve nZEB standards according to the Technical Building Code (Código Técnico de la Edificación). As mentioned on section 3.2, we must comply with the articles on the DB-HE document.

However, we want to focus on the energy analysis and not in the specific rules of the document. Therefore, we will explain the different energy solutions applied to the house although all the requirements have been met as it can be seen in the files on the annex of this document.

6.1. Building envelope

The building envelope is a substantial factor in order to reduce energy consumption. There are several factors to consider, such as the shape of the house, its location, orientation, thermal insulation, etcetera. The design of the building envelope must also take into account the expectations and demands of the owners.

6.1.1. Building shape

The geometry of the house is an important aspect when considering energy performance. This house is located in a cold climate area, so a high amount of energy is needed to heat the building. Therefore, we need to reduce the surface in contact with the exterior, as it is where energy exchange takes place.

To measure the compactness of the building we are going to use the total Heat Loss Form Factor:

$$Heat\ Loss\ Form\ Factor = Heat\ Loss\ Area\ /\ Treated\ Floor\ Area \qquad (6.1)$$

The Heat Loss Form Factor is a number generally between 0.5 and 5, with a lower number indicating a more compact building. Passivhaus buildings aim to achieve 3 or less. Once the Form Factor is over 3, achieving the Passivhaus Standard efficiently becomes more challenging.

In our building, the treated floor area is 139,2 m^2. To compute the Heat Loss Area, we sum all the walls in contact with the exterior air included the roof (358,6 m^2), the windows and the door (35,9 m^2), so Heat Loss Area equals 394,4 m^2. Therefore, the Form Factor is 2.8 that is below 3.

6.1.2. Building orientation

The building orientation will be determined considering the solar radiation captured throughout the windows, openings and roofs.

We will use the trajectory and elevation of the sun during the year. It has been found using the website SunEarthTools and it is shown in the figures following.

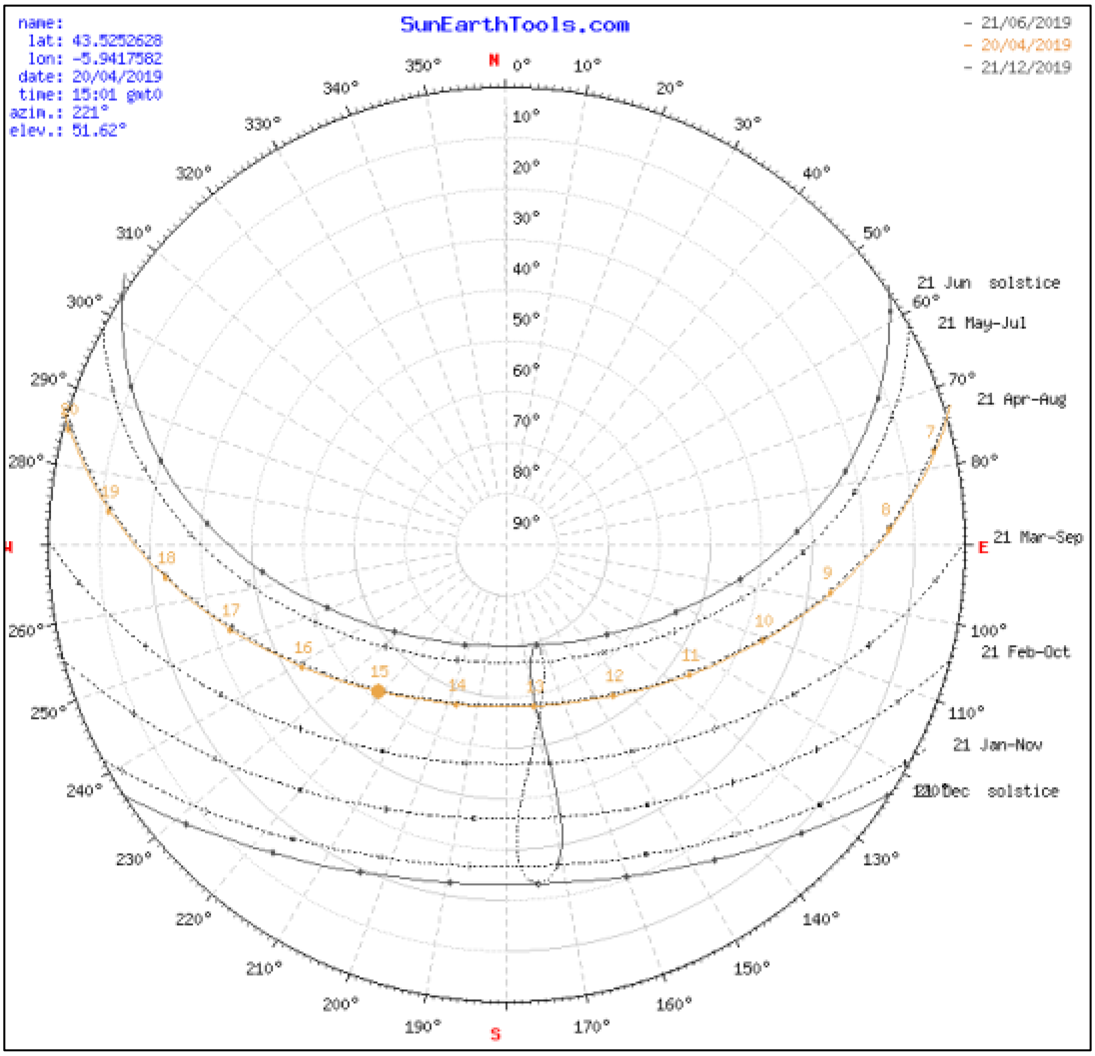

Figure 6.1 : Sun’s position on the site

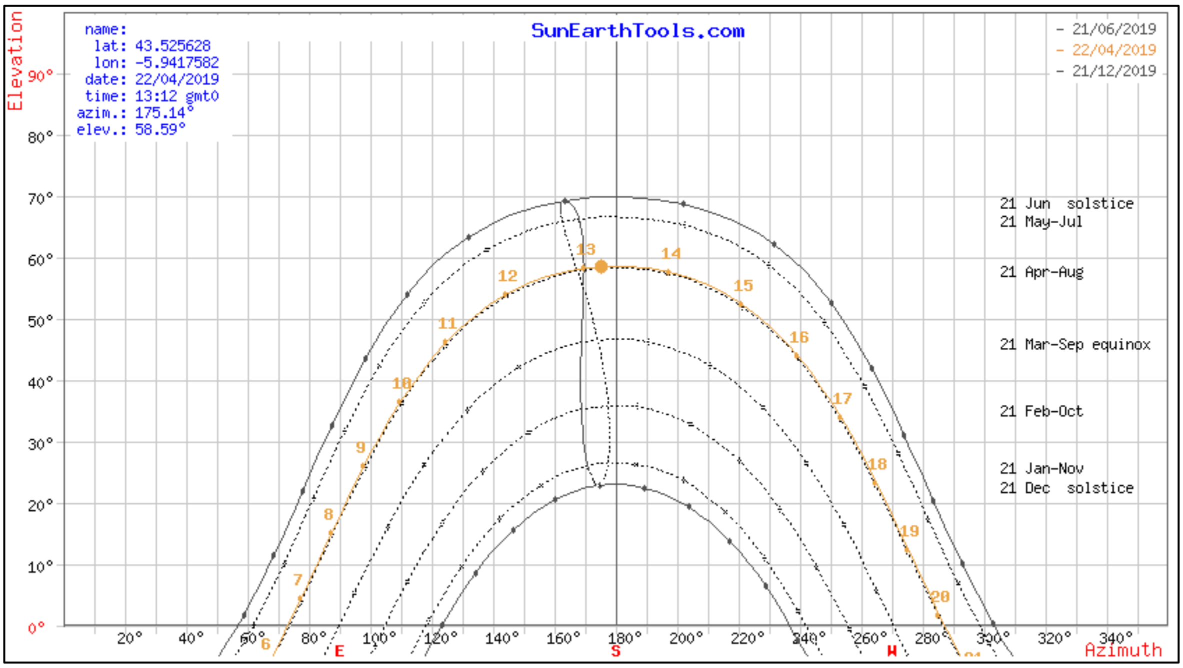

Figure 6.2 : Elevation of the sun throughout a year on the site

Analysing these figures, the plan and virtual designs of the house we explain how the main characteristics of each facade and the roof have been designed.

- **South façade**

In summer periods we have medium-high average thermal gains. But this gain will be higher during the winter period, just when in the energy field it is needed. That is why most of the windows are in this facade and its sizes are greater than in the rest. There is also a mobile porch in this facade to protect in the summer that can be remove during the winter.

- **North facade**

Solar radiation on this facade, both in summer and winter is always low, so in both seasons it will be colder than the rest. As it can be seen on *Figure 5.2*, the north facade has a few windows with small size. These have been fixed just to have natural light inside the rooms.

- **East and West facades**

Both facades receive the same solar impact. Solar radiation in these orientations will have high values in summer and medium-low values in winter although higher than the values received in the south facade. That is why there are more windows here than in the north facade but less than in the south facade. It is worth mentioning that solar radiation on the west facade coincide with the hours with higher temperatures.

- **Roofs**

The elevation of the sun in winter is low and horizontal roofs can't take much of the radiation, so inclined roofs have been designed for the house.

6.1.3. Thermal insulation

Thermal insulation in a nZEB building is vitally important due to its role on the thermal losses of the building and so on the final energy demand. It is quite obvious that we need a parameter to measure it. This parameter is the thermal transmittance coefficient, which is the factor responsible for the thermal loss trough building components.

The thermal transmittance coefficients must meet the requirements of current building regulations. These requirements are on the DB-HE document as mentioned previously. This document contains also some relevant information, such as the value of the thermal resistance of exterior and interior air.

Thermal transmittance coefficient is calculated using this formula:

$$\mathrm{U}\ (\mathrm{W/m^2K}) = 1\ /\mathrm{Rt} \tag{6.2}$$

R_t total thermal resistance of the constructive component [m^2K/W]

Where:

$$Rt = R1 + R2 + R3 + \cdots + Rn + Rse + Rsi \tag{6.3}$$

Rsi thermal resistance of the air in contact with the interior surface.

Rse thermal resistance of the air in contact with the exterior surface.

Rn is the thermal resistance of each layer.

The thermal resistance of a thermally homogenous layer is defined by the expression:

$$\mathrm{R} = \mathrm{e}/\lambda \tag{6.4}$$

e *thickness of the layer. [m]*

λ thermal conductivity of the layer. [W/mK]

Now that we know how thermal transmittance is computed, we can proceed to observe the values. All of them meet the regulations in the DB-HE document. These values have been obtained using the computer programme CERMA.

	Surface [m^2]	**Transmittance [W/m^2·K]**
Roofs	120,1	0,22
Exterior wall 1	156,3	0,17
Exterior wall 2	60,2	0,21
Wall in contact with ground	22,1	0,32
Floor	139,2	0,32

Table 6.1 : Transmittance values for the envelopment.

The materials used to achieve this thermal isolation are the following:

- **Insulation XPS**: Extruded polystyrene (XPS) foam is a rigid insulation formed with polystyrene polymer and manufactured using an extrusion process. It is the most important insulation part on the floor.

- **Mineral wool**: The exceptional thermal, fire and acoustic properties of mineral wool derive from the mat of fibres that prevents the movement of air, and from mineral wool's inert chemical composition.

- **Insulation EPS**: Expanded polystyrene (EPS) composition is about 95% polystyrene and 5% gas. It has properties similar to insulation XPS but their manufacturing processes are different. Usually, XPS is used in places that can be wet.

Another fact to be considered is the humidity condensation that could damage the thermal properties of the different materials of the envelopment. To check that the house meets with the humidity condensation regulations an excel published for the CTE has been used. These calculations are in the annex.

6.2. Energy efficiency of the lighting installation

The house doesn’t have to comply with any requirement for the lighting installation. However, a lower consumption lighting system has been installed to reduce electricity consumption. Low consumption lighting has been installed in all interior areas.

6.3. Thermal installation

It is established by the CTE document that buildings with domestic hot water demand will have to cover a part of it with the incorporation of lower temperature solar energy systems. These must be adapted to the global solar radiation of the site and the demand of domestic hot water.

On this project, this energy consumption is covered with a highly efficient air/water heat pump that is considered as renewable energy because of its high performance. Biomass technology is also used for heating.

6.3.1. Air/water heat pump

The installation of an air/water heat pump rather than a solar thermal installation is for some good reasons. It can supply a 100% of the demand of domestic hot water while solar thermal installations can supply only a 40%. The initial inversion is also cheaper, it can represent a reduction of a half of the price.

The air/water heat pump selected is the *aroTHERM VWL 55/2 A,* with the following specifications:

- Nominal thermal power: 4.5 KW
- COP (Coefficient of Performance): 4.5
- SPF (Seasonal Performance Factor): **3.038**

Figure 6.3: aroTHERM VWL 55/2 A [11]

Heat pumps are considered a source of renewable energy if the SPF is higher than 2.5. The SPF of the selected heat pump, 3.038, is greater than 2.5. To understand how this machine works we should look at the operating principles of aerothermal technology.

Aerothermal technology is a heating and sanitary hot water generation equipment based on extracting free energy from the outside air (environment) by means of an inverter heat pump. Then, the energy extracted from the outside air goes to a water circuit responsible for the heating of the house and at the same time supplying the hot water domestic circuit. On the picture below we can see a representation of it, that has been combined with a solar thermal installation.

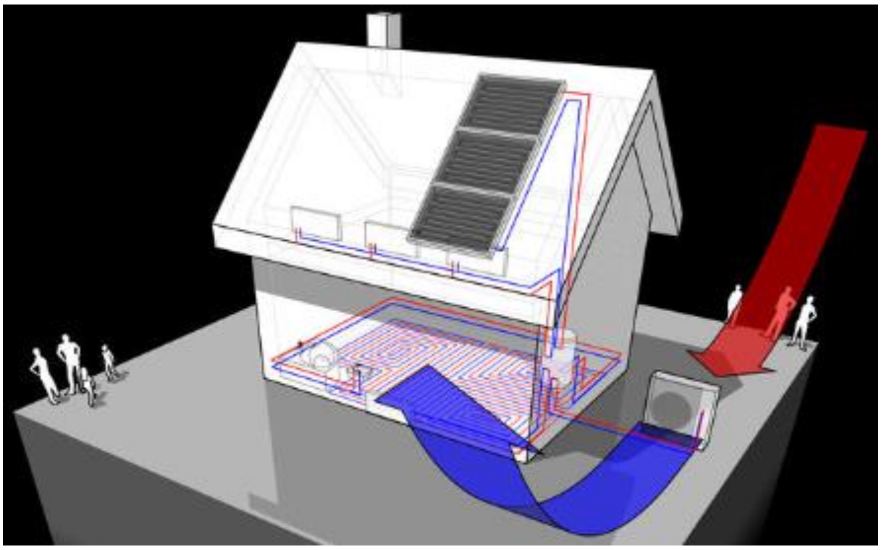

Figure 6.4: Heating system with aerothermal and solar thermal installations [10]

We must remember that any gas (air) that is at a temperature above absolute zero contains energy. That energy is what our equipment captures throughout the year. This thermodynamic system explains why, in climates without too much hours of sun light, this system is preferred to solar thermal installations.

The general parts of the system are the following:

- **Outdoor unit** where the energy of the external air is absorbed by a refrigerant.
- **Cooper pipes** to connect the indoor unit with the exterior one. In the indoor unit the refrigerant gas circulates through the pipe, where heat condenses it and it is returned to the outdoor unit as a liquid.
- **Interior unit** acts as a condenser yielding heat to the water that is distributed by the heating system, whether underfloor heating, radiators, etc.

6.3.2. Biomass

The term biomass is a generic concept that encompasses the use of any material of animal or vegetable origin with the purpose of generating energy, usually by combustion. It is used for energy production and also in several industrial processes as raw material for a range of products.

In this project biomass is used as another source of energy for the heating of the house. In general, it is assumed that it has a 90% performance. Moreover, it is a clean energy because carbon emissions are of vegetable origin. That’s the main reason why it is considered a renewable source of energy as it avoids burning toxic combustibles, such as the natural gas that it has been used on conventional boilers.

We can’t measure the exact nominal power because it depends on the owners’ use, but it is clearly a good option to help heat the house in the coldest months.

7. Photovoltaic System Design

The Photovoltaic installation must supply the electricity for all the electrical appliances, lighting and heating. Electricity consumption is variable, so we must approximate our calculations.

The first step involves listing all the loads in a so-called load table, to determine the total demand in watt hour per day. This table basically contains information about the loads that will be connected to the PV system. The energy requirements of the loads are calculated by filling out details such as device type, rated power and average daily operational time,

The total energy requirement of the respective loads is calculated by multiplying the power rating of the load by its average daily operational time. Once all the demand for the electrical appliances have been calculated we add all these demands and we multiply this sum by 1.1, this factor represents the standby consume, to achieve a more accurate result.

We can see the table load calculated for the house on *Table 7.1* below.

It should be observed that in this table lighting and heating have only the final consumption on watt-hour per day column, that's because they have been calculated in a different way.

The lighting installation of the house has a lower consumption system. Therefore, we make an estimation of the energy amount used for the lighting consumption of 600 Watts-hr per day. We have considered that the consume of each light is around 7 or 11 watts and also according to the *Instituto para la Diversificación y Ahorro de la Energía (IDAE)* each house uses 23 lights.

Finally, we find the electricity consumed by the boil heater and domestic hot water as follows:

- Boil heater

The annual demand is 7.98 $Kw \cdot h/m^2 \cdot year$ and the surface of the house is 147.9 m^2. We multiply this two numbers and divide the result by the Coefficient of performance (COP) of the heat pump. Finally, we convert this result to watt-hr per day.

- Domestic hot water

$$Energy\ demand = Consumption\ of\ DHS * Thermal\ jump\ on\ the\ water * 1{,}16 \qquad (7.1)$$

$$Consumption\ of\ DHS\ =\ 4\ persons\ *\ 28 litres/person\ =\ 1116\ litres \qquad (7.2)$$

The thermal jump of the water is 60 degrees minus 13,4 degrees that is the current temperature that arrives to the house.

The energy demand is 6054,27 watts-hour per day.

The electrical consume is the value of the energy demand divided by the COP coefficient, so in this case, the heat pump electrical consume for the domestic water is 1345,28 watt-h per day.

Finally, having all the electrical consumptions we obtain the total daily energy requirement of the loads: 14633 watts-h per day.

All calculations have been compared with the sources of information from IDAE to achieve a more accurate result.

Device	Quantity	Hours of Daily use	Device Watts	Watt-hr per day
Kitchen				
Toaster	1	0,25	1500	375
Fridge	1	24	75	1800
Freeze	1	24	65	1560
Coffee machine	1	0,15	1000	150
Dishwasher	1	1	650	650
Microwave	1	0,3	850	255
Oven	1	0,5	1300	650
Extractor Fan	1	1	15	15
Ceramic Stove	1	1	1200	1200
Laundry				
Washing Machine	1	1,5	600	900
Clothes Dryer	1	1	1000	1000
Iron Box	1	0,25	1200	300
Living room and bedrooms				
Television	2	2	170	680
Video Game Console	1	2	150	300
Satellite Receiver	1	2	25	50
Smartphone- Recharge	3	4	6	72
Tablet-Recharge	2	3	8	48
Printer	1	0,25	100	25
Desktop Computer	1	1	200	200
Laptop- Charger	2	2	65	260
Miscellaneous				
Electric Shaver	1	0,25	15	3,75
Vacuum	1	0,25	350	87,5
Hair dryer	1	0,25	1200	300
Lighting				
Lighting		-	-	600
Heating				
Boil Heater		-	-	718,56
Domestic Hot Water		-	-	1345,28
Total				
				14633
				(Wh/dia)

Table 7.1 : Load table

7.1. Equivalent Sun Hours

The Equivalent Sun-Hours (ESH) on the location of the building are needed to find the power of the PV system. The definition of an equivalent sun-hour is an hour during which the intensity of sunlight is 1000 watts per square meter. This is one of the most important parameters that determine the size of the installation and it is used to measure how much solar energy is available in an area during a usual day.

Terrestrial solar radiation varies both in intensity and spectral distribution depending on the geographical location and the position of the Sun in the sky. Each place has a different value of ESH. There are different sources of information, here we have used the data published by the National Agency of Meteorology of Spain, called AEMET, because it contains a total of 22 years of data (1983 to 2005).

We have used the data corresponding to the city of Oviedo,18 kilometres away of the house.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ESH (Kwh/m^2)	1,77	2,43	3,6	4,46	4,99	5,34	5,29	4,8	4,1	2,74	1,87	1,49

Table 7.2 : Table with the Equivalent Sun Hours according to AEMET.

The EHS for a year according to the above table is 3.57.

It has also been considered the possibility to calculate the ESH using the PVGIS software, developed by the European commission, but it contains less years of information. However, this tool has been used to check that the ESH in Oviedo and in the house are the same. For example, on 2007 the difference was just 1,32%.

To achieve a more accurate number of the ESH several specific factors must be considered as they are different in each installation.

- Reflective surfaces close to the installation
- Presence of natural or artificial elements that could shadow the panels
- Atmospheric effects
- Orientation and inclination of the panels

There are no reflective surfaces close to the installation, as the house is located on the countryside, not in the middle of a city. There will be no effect on the irradiation received. If elements with this property are introduced close to the house in the future, it could have a positive effect because the panels could receive a higher amount of solar irradiation.

There are no natural or artificial elements that could shadow the panels.

The atmospheric effects have been checked and they don't change the ESH because the place is considered meteorologically favourable to the installation of a PV system. For example, the panels are cleaner than in other places because here it rains often and snow, that could cover the panels, is very rare. Another important factor temperature but will be considered later in the study of the inverter, where it takes more relevance.

The orientation and inclination of the panels is treated in more detail in the following sections.

7.1.1. Azimuth Angle

The azimuth angle α, is defined as the angle between the projection on the horizontal plane from the normal to the surface of the module and the meridian of the place, as we can see on Figure 7.1 : Representation of Azimuth Angle Its value is 0 ° for modules oriented to the South, -90 ° for modules oriented to the East and +90 ° for modules oriented to the West.

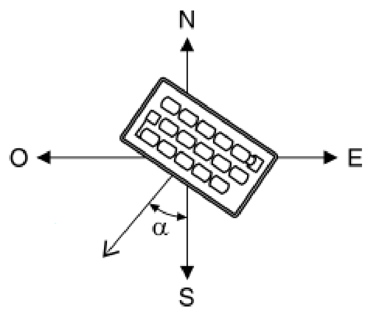

Figure 7.1 : Representation of Azimuth Angle

On this project the azimuth angle is determined by the orientation of the roof. The PV panels will be on the roof facing to the south where they will have the best solar irradiance.

7.1.2. Tilt angle

The tilt angle β, is defined as the angle that forms the surface of the modules with the horizontal plane, as we can see on Figure 7.2 . Its value is 0º for horizontal modules and 90º for vertical modules.

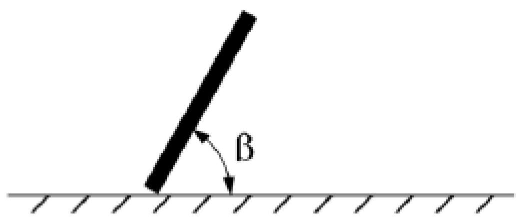

Figure 7.2 : Representation of tilt angle

The optimum tilt angle depends on the location. Some software tools can be used to find it, such as the PVGIS tool that defines as the optimum tilt angle for this house to 36º. But in this case, there is no need to find it because the PV system is built integrated in the roof, so the tilt angle is the same of the inclination of the roof, that is 10º.

In order to find the correction for ESH we use a correction table for our latitude. On this table we find a number for each month and each tilt angle.

Latitud = 43°

Inc	Ene	Feb	Mar	Abr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic
0	1	1	1	1	1	1	1	1	1	1	1	1
5	1.08	1.07	1.05	1.03	1.02	1.02	1.02	1.04	1.06	1.08	1.1	1.09
10	1.15	1.12	1.09	1.06	1.04	1.03	1.04	1.07	1.11	1.16	1.19	1.18
15	1.22	1.18	1.13	1.08	1.05	1.03	1.05	1.09	1.15	1.23	1.27	1.26
20	1.28	1.22	1.16	1.09	1.05	1.03	1.05	1.1	1.19	1.29	1.35	1.33
25	1.33	1.26	1.18	1.1	1.04	1.02	1.04	1.11	1.22	1.34	1.42	1.4
30	1.37	1.29	1.2	1.1	1.03	1	1.03	1.11	1.24	1.38	1.48	1.45
35	1.41	1.31	1.2	1.09	1.01	.98	1.01	1.1	1.25	1.42	1.52	1.5
40	1.43	1.33	1.2	1.07	.98	.95	.98	1.09	1.25	1.44	1.56	1.54
45	1.45	1.33	1.19	1.05	.95	.91	.95	1.06	1.24	1.45	1.59	1.57
50	1.46	1.33	1.17	1.02	.91	.87	.91	1.03	1.23	1.46	1.61	1.58
55	1.46	1.32	1.15	.98	.86	.82	.86	1	1.21	1.45	1.62	1.59
60	1.45	1.3	1.12	.94	.81	.76	.81	.95	1.17	1.44	1.62	1.59
65	1.43	1.27	1.08	.89	.75	.7	.75	.9	1.13	1.41	1.61	1.58
70	1.41	1.23	1.03	.83	.69	.64	.69	.84	1.09	1.38	1.58	1.56
75	1.37	1.19	.98	.77	.62	.57	.62	.78	1.03	1.34	1.55	1.53
80	1.33	1.14	.92	.7	.55	.49	.55	.71	.97	1.28	1.51	1.49
85	1.28	1.08	.85	.63	.47	.42	.47	.64	.9	1.22	1.45	1.44
90	1.22	1.02	.78	.56	.4	.34	.39	.56	.83	1.16	1.39	1.38

Table 7.3: Correction parameter values for the ESH. [12]

The ESH is multiplied by the correction factor to find a more accurate ESH.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ESH (Kwh/m^2)	1,77	2,43	3,6	4,46	4,99	5,34	5,29	4,8	4,1	2,74	1,87	1,49
Correction factor	1,15	1,12	1,09	1,06	1,04	1,03	1,04	1,07	1,11	1,16	1,19	1,18
Final ESH(Kwh/m^2)	2,04	2,72	3,92	4,73	5,19	5,50	5,50	5,14	4,55	3,18	2,23	1,76

Table 7.4: Final ESH for each month

The ESH for a year according to the above table is 3.87. This is the new value for ESH that is used on the project to size the PV system.

7.2. Photovoltaic system sizing

To define the size of the photovoltaic panels and the inverter, the ESH and the daily electrical consumption of the house computed before will be used.

7.2.1. Photovoltaic panels

The market offers a wide range of photovoltaic panels. A panel with high power has been chosen because the roofs limit the space available for the PV system.

The photovoltaic panel used in this project is the Sun Power SPR-X21-345 power model.

Electrical Data	
Nominal Power (Pnom)	345 W
Power Tolerance	+5/0%
Panel Efficiency	21.2%
Rated Voltage (Vmpp)	57.3V
Rated Current (Impp)	6.02 A
Open-Circuit Voltage (Voc)	68.2 A
Short-Circuit Current (Isc)	6.39 A

Table 7.5: Electrical data of the SPR-X21-345 power model.

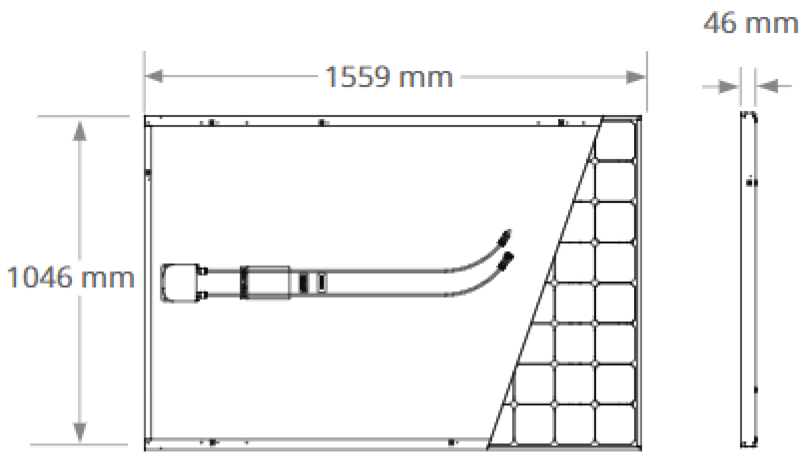

Figure 7.3: Physic dimensions of the PV module.

The photovoltaic generation has been sized using the following calculations:

$$Minimum\ Wp = \frac{E_{demand} \cdot LF}{ESH_{corrected}} = \frac{14633 \cdot 1.2}{3.82} = 4596\ W \qquad (7.3)$$

Minimum Wp	Total minimum watt-peak needed for PV modules
E_{demand}	Total energy demand of the house
LF	Loss factor caused by efficiency of the inverter, dust on PV modules, heat losses on conductors, etc.
$ESH_{corrected}$	ESH corrected with all factors specified before.

$$N_p = \frac{Minimum\ W_p}{P_{nom}} = \frac{4596}{345} = 13.32 \qquad (7.4)$$

Np	Total number of photovoltaic panels
Pnom	Nominal power of the PV module

The loss factor (LF) has been calculated considering the following:

- Performance of the inverter
- Losses due to dust in the panels
- Temperature losses
- Losses on the conductors

Finally, the total number of photovoltaic panels is 13.32 according to the calculations, so the PV system needs a total of 14 panels. The surface needed for the panels is equal to 22.82 m^2 and the roof has 54.375 m^2, so the panels can be fixed in this roof.

7.2.2. Inverter

As the PV system is connected to the grid, there are three constrains that will affect the selection of the inverter:

- The output power of the inverter must be between 0.9 to 0.96 of the solar array peak power. (0.9×4830=4347 and 0.96×4830=4636.8)

$$4347\ W < \ Output\ power\ of\ the\ inverter\ < 4636.8\ W \tag{7.5}$$

- The solar array's maximum voltage must be lower than the inverter's maximum input DC voltage. Therefore, we will connect 2 branches in parallel with 7 modules in series each.

$$V_{MP} \cdot n_{sp} = 401.1V \ < V_{IN,max(abs)} \tag{7.6}$$

V_{MP}	Solar module maximum voltage
n_{sp}	PV modules in series
$V_{IN,max(abs)}$	Inverter's maximum input DC voltage

- The maximum current of the PV array must be below the inverter's maximum input current. The number of branches in parallel is correct if this condition is satisfied.

$$I_{mp} \cdot n_{pp} \ = 6.02 \cdot 2 = \ 12.04 < \ I_{MPPT,max} \tag{7.7}$$

Imp	Maximum power current
n_{pp}	total of parallel branches
$I_{MPPT,max}$	Inverter's maximum input DC current

The sub index MPPT indicates maximum power point track. The inverter has an algorithm that finds the maximum power point, so it increases the efficiency of the PV system. This algorithm ensures that the PV part is always working to the maximum power point.

All this information has been taken into account and the inverter used for this project is the model UNO-DM-4.6-TI-PLUS-Q.

Electrical Data	
Input	
Nominal Input Power ($P_{DC,r}$)	4750 W
Maximum power input ($P_{DC,max}$)	4750W
Maximum input voltage ($V_{IN\ max\ (abs)}$)	600V
Maximum current MPPT ($I_{MPPT,max}$)	16 A
Short circuit current MPPT (I SC max)	20 A

Output	
Rated active power ($P_{AC,r}$)	4600 W
Maximum active power ($P_{AC,max}$@cosφ=1)	4600 W
Rated voltage ($V_{AC,r}$)	230 V
Nominal frequency(fr)	50 Hz
Maximum current ($I_{AC,}$max)	20 A
Maximum efficiency	97%

Table 7.6: Electrical data of the inverter

The inverter will be installed in a habilitated area in the house.

8. Electrical Installation

The electrical installation must meet the regulations established in the electrical engineering low voltage regulation (Reglamento Electrotécnico de Baja Tension, REBT). The general aspects of the electrical installation are analysed here.

8.1. Measuring equipment

The installation must comply with the measuring rules exposed in the Royal Decree 244/2019, so the following device is needed.

- Bidirectional measurement device, which calculates the electricity that the installation sends to the grid and the energy consumed in the building

Apart from this device is included a monitor system is required with the purpose of helping the owners and the maintenance team know, at any time, the operating conditions. This system includes the following features:

- Meteorological data of the site (solar irradiation and temperature of panels)
- Data of the production generated by the photovoltaic system, such as:
    - Voltage on the direct current side, that is at the entrance of the inverter
    - Total power at the source of the inverter
    - Reactive power at the source of the inverter
- Billing
- CO_2 reduction

Figure 8.1 : Monitoring system by SMA

8.2. Protections

Protections for the installation are designed in compliance with the Royal Decree 1699/2011 and the Royal Decree 1110/2007. Some of the main devices on the installation are the following:

- **General cut-off switch** that gives complete isolation to protect the workers against electrical risk.

- **Automatic differential switch,** with the purpose to protect people in case of a deviation through some grounded element.

- **Automatic switch,** the automatic connection-disconnection of the installation in case of anomaly on the tension or frequency on the grid. This function can be taken by the switch or switches in the generation equipment.

- **Protection of the maximum/minimum frequency connection, and the maximum/minimum tension between phases.**

- **Class II Isolation:** to protect the photovoltaic grid against possible transitory overvoltage caused by indirect atmospheric discharges near the photovoltaic installation.

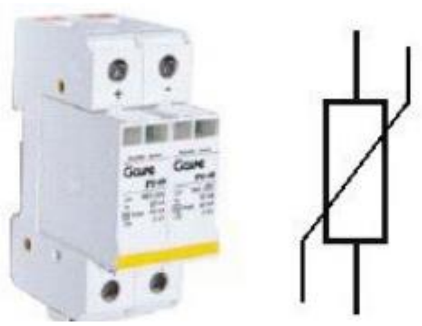

Figure 8.2 : Class II isolation and the normalized symbol

8.3. Earth connection

According to the Royal Decree 1699/2011, some general conditions that the earth connection installation must comply with are the following:

- The earth connection on the interconnected installations must be done in a way that the conditions of the earth connection of the distribution company can't be altered, ensuring that possible defects are not transferred to the distribution network.

- The installation must have a galvanic isolation between the distribution network and the generating facilities

- The masses of the generating facility will be connected to an earth independent of the distribution company neutral.

8.4. Cables

All aspects related to cables must comply with the rules of the Royal Decree 842/2002, specifically the ITC-BT-19 document.

As current flows through a wire, some energy is always lost into heat. The power dissipated on the cable is a function of the current, thickness, length and the material.

$$\mathrm{P_{lost}} = \mathrm{I}^2 \cdot \mathrm{R_{cable}} = \frac{\mathrm{V_{cable}}^2}{\mathrm{R_{cable}}} \quad (8.1)$$

$$R_{cable} = \rho \cdot \frac{L}{A} = \frac{1}{\sigma} \cdot \frac{L}{A} \quad (8.2)$$

A	cross sectional area
σ	conductivity
L	length of the cable
ρ	resistivity

In general, using short and thick cables reduces power loss but this is expensive. To reduce economic cost, we will use cables as thin as possible but meeting the power requirements of our system.

8.4.1. Cross sectional area of cables

Calculation of the cross-sectional area in sections of *direct current*:

$$S = \frac{2 \cdot L \cdot Icc}{u \cdot C} = \frac{2 \cdot 30 \cdot 6.39}{0.02 \cdot 401.1 \cdot 59} = 0.81 mm^2 \quad (8.3)$$

S	theoretical cross sectional area (mm^2).
L	cable length (m).
Icc	maximum current flowing through panels and is equivalent to short-circuit current of panels (A).
u	maximum drop voltage for cables.
C	conductivity of the cable ($m/\Omega \cdot mm^2$)

- The estimated length of the cables is 30 metres. This corresponds to the distance between the panels and the inverter.

- The conductivity of the cable is equal to 56 because the conductor material is copper.

- The maximum drop voltage for cables according to the regulation is 3%. In this case we choose a 2% of drop voltage for cables. So, we multiply 0.02 by 401.1V that correspond to the voltage generated by the panels.

Calculation of the cross sectional area in sections of *alternate current*:

$$S = \frac{2 \cdot L \cdot P}{U \cdot C \cdot u} = \frac{2 \cdot 12 \cdot 4600}{230 \cdot 56 \cdot 0.02 \cdot 230} = 1.86\, mm^2 \quad (8.4)$$

S	theoretical cross sectional area (mm^2)
L	cable length (m)
P	maximum power that the cable can transport (W)
u	maximum drop voltage for cables.
U	voltage for cables
C	conductivity of the cable ($m/\Omega \cdot mm^2$)

- The estimated length of the cables is 12 metres. This corresponds to the distance from the panels to the connection point to the grid.

- The conductivity of the cable is equal to 56 because the conductor material is copper

- The maximum drop voltage for cables according to the regulation is 3%. In this case we chose a 2% of drop voltage for cables. So, we multiply 0.02 by 230V that correspond to the working voltage in European houses.

As a result, the cables used for the whole installation are type PV ZZ-F cables, made of copper, and specially designed for photovoltaic installations, since they are unipolar cables with double insulation and with great resistance to weather conditions.

9. Regulations

There are two blocks of regulations affecting this project.

- Regulations related to photovoltaic installations of low power and connected to the grid:

  - **Royal Decree 244/2019 of 5 April,** by which the administrative, technical and economic conditions of the self-consumption of electrical energy are regulated.
  - **Royal Decree 242/2018 of 5 October,** with urgent measures for the energy transition and the protection of consumers.
  - **Royal Decree 1699/2011 of 18 November,** which regulates the connection to the grid of low-power installations that produce electrical energy.
  - **Royal Decree 1110/2007 of 24 August,** by which the regulation of unified points of measurement of the electrical system is approved.
  - **Royal Decree 842/2002 of 2 August,** which regulates the Electrical engineering rules for low tension.
  - **Institute IDAE, Specifications of Technical Conditions for the Grid Connected Installations, on July 2011.**

- Rules related to the nZEB standards and technical characteristics of buildings:

  - **DB-HE, Basic document for energy savings,** which aims to establish rules and procedures that allow to meet the basic requirements of energy savings.
  - **Support documents for the DB-HE,** such as DB-H1 to calculate the parameters for the envelope.
  - **Royal Decree 235/2013, of 5 April,** by which the basic process for the certification of the energy efficiency of the buildings is approved.

10. Environmental Impact

According to the Cambridge dictionary the environmental impact is defined as '*the effect that the activities of people and businesses have on the environment'*.

In this project we need to consider the environmental impact of the house and the solar installation.

- **Environmental impact of the photovoltaic system**

The photovoltaic systems offer significant environment benefits compared to the conventional energy sources. The electricity generated is clean, non-polluting and sustainable, thus resulting in no global warming emissions.

According to IDAE each Kwh generated with photovoltaic energy avoids 1 Kg of CO_2 compared to electricity generation with coal. This photovoltaic installation avoids the emission of 5.341 tons of CO_2 per year compared to a conventional electrical installation.

Like all energy sources this system has an environmental impact. The potential environmental impacts are associated with:

- **Land use and visual impact**: In this case it is a built-integrated system, so it has a minimum impact.
- **Use of water**: Water is not used to clean the panels. There is no impact due to water use.
- **Natural resources**: Although common minerals are required to produce PV panels, these materials are recyclable.
- **Hazardous materials**: The manufacturing and maintaining processes of photovoltaic panels and associated components (e.g. inverters) use a few hazardous materials. The release of these hazardous materials to the environment is frequently considered to be the most critical negative environmental impact of PV systems. Most of them are used to clean and purify the semiconductor surface of photovoltaic cells. However, manufacturers have a strong financial incentive to ensure that these highly valuable and often rare materials are recycled rather than thrown away.

- **Environmental impact of the house and its related consumptions**

The major impacts of the house are the land use, the visual impact, and the materials used to build the house. Although the environmental impact is small, it must be considered. The related consumptions in the house must also be taken into account.

We have studied the water/air heat pump and the biomass generator, to the conclusion that according to the manuals of the IDAE, the CO_2 emissions are virtually neutral.

11. Economic Viability

To know the economic viability of the project is needed to know the cost of the different elements of the photovoltaic installation in order to find the inversion.

Element	Units	€/unit	Total €
Solar Panels SPR-X21-345	14	341.65	4783.1
KIT to fix the panels	1	392.47	392.47
Inverter UNO-DM-4.6-TI-PLUS-Q	1	1048.67	1048.67
Electrical components and installation	1	2750	2357.53
Monitoring system Owl intuition	1	208.3	208.3
Hours destined for the project	1	2000	2000
Investment	-	-	**10790.03**

Table 11.1 : Cost of the different elements

The investment needed is 10790.03€ and the major cost are the solar panels. It is worth mentioning that the electrical components and installation, mentioned on the costs, include all the physical components needed for the installation and also the hours for the installation technician.

We need to compute the annual savings in order to compute the NPV, IRR and return period that have been used to know the economic viability of the project. The price of the Kw·h multiplied by the total annual consumption of the house equals to the annual savings.

$$Annual\ \mathrm{Savings} = 0.13131\frac{€}{\mathrm{Kw}\cdot\mathrm{h}}\cdot 14633\frac{\mathrm{wh}}{\mathrm{day}}\cdot 365\frac{\mathrm{days}}{\mathrm{year}} = 701.33\frac{€}{\mathrm{year}} \quad (11.1)$$

The NPV and IRR are calculated according to the useful time of the installation and panels. It has been considered 20 years. Also, we considered that the government of Spain pays a grant for the solar installations. We approximated 200 euros during the first five years and a compounded interest of 2%. This is difficult to calculate due to the economic changes throughout the years.

The NPV is equal to 450.25€ and the IRR, 4%. The return period for the investment is 13 years and 11 months. Therefore, this project is viable.

Conclusions

Once the project is finished, we proceed to select the information and results to expose the conclusions.

- The firsts objective consists on verifying that all the regulations that define an nZEB building are met. The actions derived from this objective are the following:

  - Build the envelopment of the house with isolation materials such as XPS, EPS or mineral wool.
  - Systems to reduce the electricity consumption, such as the lower consumption lighting system have been installed.
  - Use of renewable energies to supply the energy demand of the house. Thermal installation uses an air/water heat pump and biomass will be used to generate the thermal energy required.
  - The orientation of the house is important due to the thermal gains/losses of the house, as well as the position of the windows and the shape of the building.

- The second objective is to evaluate the energetic demands of the house. To obtain a good evaluation of the energetic demand, a load table that makes the calculation visually and graphically is needed. It is also necessary to contrast the information with reliable resources of information.

- The third objective is design a photovoltaic installation to cover the electrical demands of the house. To achieve this goal, we observe that there are a series of important facts:

  - The power of the system depends on the orientation and inclination of the panels which in built-integrated systems it is not optimal.
  - To size the panels and the inverters we take into account the electrical demand and the ESH. This implies that our installation is formed by 14 panels in 2 parallel branches, each one with 7 PV modules.

- The last objective proposed is to evaluate the environmental impact and the economic viability of the photovoltaic system. As we can see, the environmental impact is positive because the photovoltaic system saves 5341 tons of CO_2 per year.

  The project is economically viable because the NPV is 450.25 €, and the returnable period of the initial inversion is 13 years and 11 months.

Thank you note

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